MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2016/2017

ETM7216 – ACTIVE MICROWAVE CIRCUIT DESIGN

8 OCTOBER 2016
9.00 a.m - 12.00 p.m
(3 Hours)

INSTRUCTIONS TO STUDENT

1. This question paper consists of 9 pages with 4 questions only.
2. Answer **ALL FOUR** questions, all questions carry equal marks of 25. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Useful formulae are listed in Appendix.

Question 1

(a) Explain briefly the term *small-signal s-parameters* and *large-signal s-parameters* in high frequency transistor design. Which parameter is usually used in low noise amplifier design?

[5 Marks]

(b) A microwave bipolar junction transistor (BJT) has the following *S*-parameters at 2 GHz, with system impedance, $Z_o = 50\ \Omega$:

$$S_{11} = 0.894\angle -60.6^\circ = 0.439 - j0.779,$$
$$S_{21} = 3.122\angle 123.6^\circ = -1.728 + j2.600,$$
$$S_{12} = 0.02\angle 62.4^\circ = 0.00926 + j0.0177, \quad \text{and}$$
$$S_{22} = 0.781\angle -27.6^\circ = 0.692 - j0.362.$$

(i) Calculate the Roulette stability factor k and Δ, and state the stability condition.

[4 Marks]

(ii) Determine the center C_{out} and radius r_{out} of output stability circle

[4 Marks]

(iii) Determine the center C_{in} and radius r_{in} of input stability circle.

[4 Marks]

(c) In order to improve the stability of a BJT transistor, a shunt resistor of approximately 70 Ω is connected at the input (as shown in **Figure Q1**). The transistor has the following *S* – parameters at 2 GHz, with system impedance, $Z_o = 50\ \Omega$:

$$S_{11} = 0.65\angle -94^\circ = -0.0453 - j0.648,$$
$$S_{21} = 4.62\angle 116.2^\circ = -2.040 + j4.145,$$
$$S_{12} = 0.035\angle 41.2^\circ = 0.0263 + j0.0231, \quad \text{and}$$
$$S_{22} = 0.66\angle -36^\circ = 0.534 - j0.388.$$

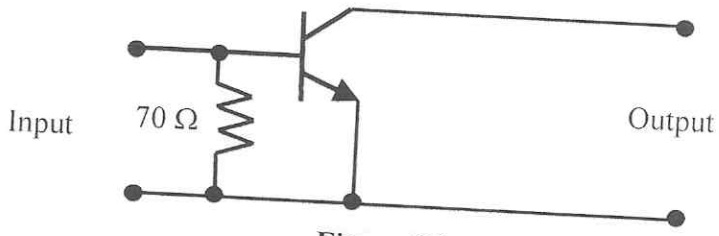

Figure Q1

(i) Calculate the Roulette stability factor k and Δ, and state the stability condition, after addition of the input shunt resistor.

[4 Marks]

(ii) Explain briefly TWO (2) advantages and TWO (2) disadvantages of adding an input shunt resistor for stabilizing an amplifier.

[4 Marks]

Question 2

(a) Define and illustrate with a suitable diagram the small-signal transducer power gain G_T, available power gain G_A, and power gain G_P of an amplifier. Show that $G_T \leq G_A$ and $G_T \leq G$, where G_T is the transducer power gain, G_A is the available gain and G is the power gain.

[8 Marks]

(b) A microwave transistor amplifier has the following S-parameters ($Z_o = 50\ \Omega$) measured at 5 GHz.

$$S_{11} = 0.641\angle -171.3^\circ = -0.634 - j0.097,$$
$$S_{21} = 2.058\angle 28.5^\circ = 1.809 + j0.982,$$
$$S_{12} = 0.057\angle 16.3^\circ, = 0.0547 + j0.0160 \quad \text{and}$$
$$S_{22} = 0.572\angle -95.7^\circ = -0.0568 - j0.569.$$

(i) Define the terms *unconditional stability* and *conditional stability* for a transistor amplifier.

[4 Marks]

(ii) Calculate the Roulette stability factor k and Δ, and state the stability condition.

[3 Marks]

(iii) Determine the reflection coefficients for simultaneous conjugate match, Γ_{Sm} and Γ_{Lm}.

[6 Marks]

(iv) Calculate in decibel (dB), the maximum stable gain for this amplifier.

[2 Marks]

(v) Calculate in decibel (dB), the maximum transducer power gain for this amplifier.

[2 Marks]

Question 3

(a) Draw THREE (3) resistive negative feedback topologies for both the Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET) for broadband amplifier.

[6 Marks]

(b) A two-stage power amplifier consisting of first stage pre-amplifier and second stage power amplifier for linear operation at 3 GHz, is to be designed and then connected to a band pass filter with insertion loss of 3 dB within passband. The input signal power is 0 dBm. The gain and input power relationships for amplifiers **Amp_A** and **Amp_B** at 3 GHz are shown in **Figure Q3**. One will be used as pre-amplifier while the other will be the power amplifier.

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(i) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_A**.

[4 Marks]

(ii) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_B**.

[4 Marks]

(iii) Which amplifier is suitable for the first stage? Explain your answer.

[2 Marks]

(iv) Which amplifier is suitable for the second stage? Explain your answer.

[2 Marks]

(v) Calculate the power gain, G_1 in dB and output power, P_1 in dBm obtained after the first stage.

[2 Marks]

(vi) Calculate the power gain, G_2 in dB and output power, P_2 in dBm obtained after the second stage.

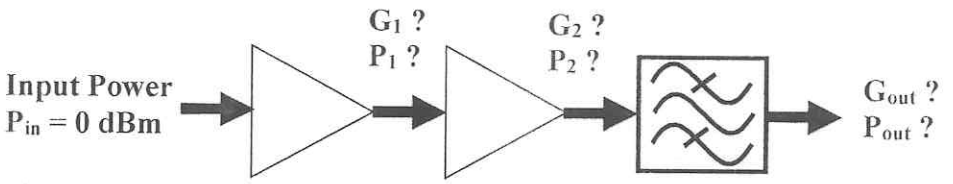
[2 Marks]

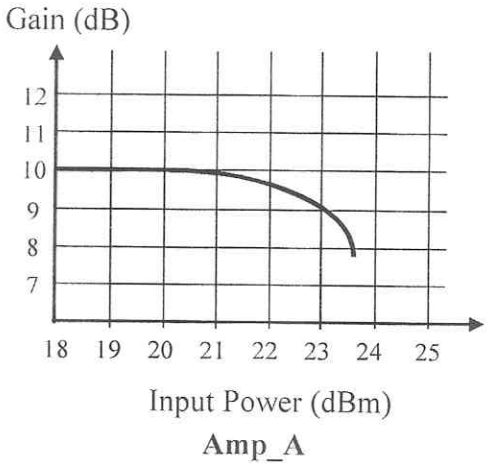
(vii) What is the main function of the band pass filter after the amplifiers?

[1 Mark]

(viii) Calculate the final power gain, G_{out} in dB and output power P_{out} obtained from this design.

[2 Marks]





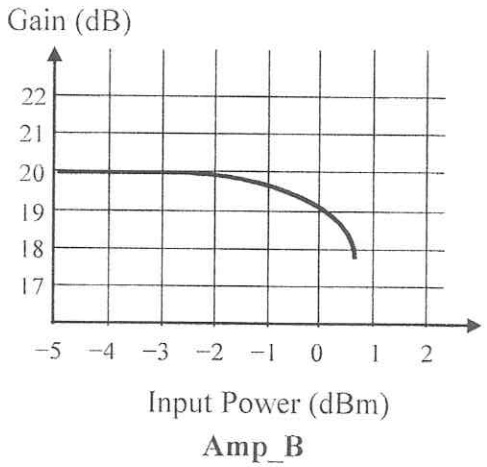


Figure Q3

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Question 4

(a) The S – parameters of a BJT in a common base configuration is measured at 4.0 GHz and has the following values ($Z_o = 50\ \Omega$)

$$S_{11} = 0.72\angle{-116°} = -0.316 - j0.647,$$
$$S_{21} = 2.60\angle{76°} = 0.629 + j2.522,$$
$$S_{12} = 0.03\angle{57°} = 0.0163 + j0.0252, \quad \text{and}$$
$$S_{22} = 0.73\angle{-54°} = 0.429 - j0.591$$

(i) Calculate the Roulette stability factor k and Δ, and state the stability condition. [3 Marks]

(ii) Can this transistor (in common base configuration) be used as an oscillator? [2 Marks]

In order to increase the instability, a lumped component is connected to the base of the transistor as shown in **Figure Q4**. The new S-parameters of this configuration are measured at 4.0 GHz and have the following values ($Z_o = 50\ \Omega$)

$$S'_{11} = 1.118\angle{165.6°} = -1.082 + j0.280,$$
$$S'_{21} = 2.068\angle{-12.72°} = 2.017 - j0.455,$$
$$S'_{12} = 0.162\angle{166.9°} = -0.158 + j0.037, \quad \text{and}$$
$$S'_{22} = 1.154\angle{-3.57°} = 1.152 - j0.072$$

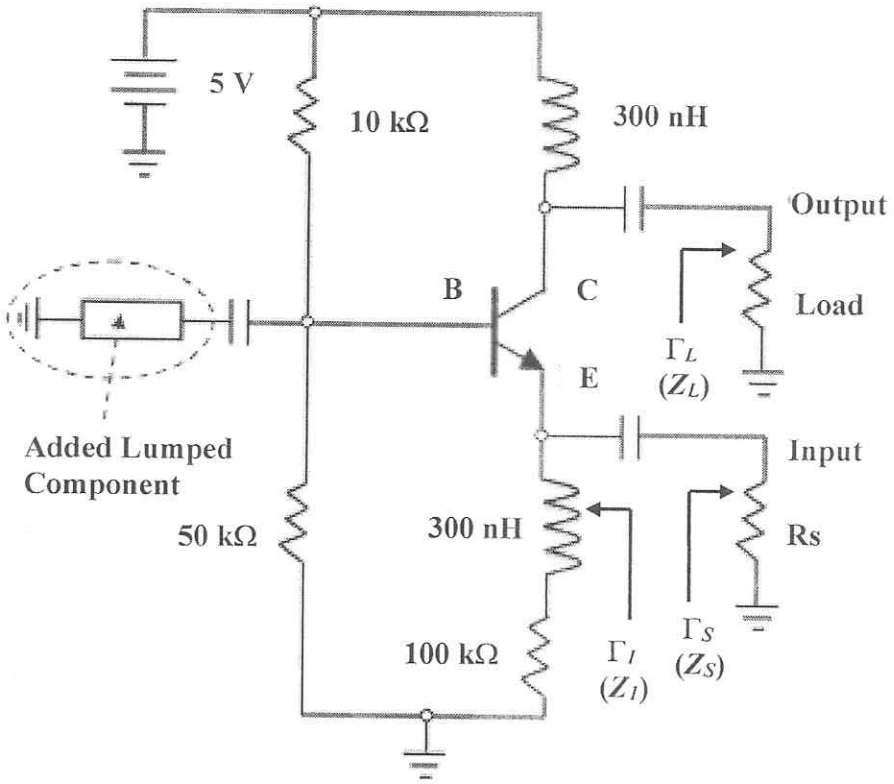

Figure Q4

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(iii) What is the suitable lumped component to be added in this configuration? [2 Marks]

(iv) Calculate the Roulette stability factor k and Δ, and state the stability condition. [4 Marks]

(v) Can this configuration be used to design an oscillator? [2 Marks]

(vi) Calculate the center C_{in} and radius r_{in} of the input stability circle and plot this circle on a Smith chart and identify the stable and unstable regions. [4 Marks]

(vii) Calculate the center C_{out} and radius r_{out} of the output stability circle and plot this circle on a Smith chart and identify the stable and unstable regions. [4 Marks]

(viii) With the suggested value of load reflection $\Gamma_L = 0.5 \angle 0°$ (or $Z_L = 150 + j0$ Ω), calculate the input impedance, Z_I and source impedance, Z_S that would satisfy the unstable operating condition of the oscillator. [4 Marks]

APPENDIX

Given:

Input and Output reflection coefficient

$$\Gamma_1 = \Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \qquad \Gamma_2 = \Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

Power Gain, Available Gain and Transducer Gain

$$G_p = \frac{|S_{21}|^2\left(1 - |\Gamma_L|^2\right)}{\left(1 - |\Gamma_{in}|^2\right)|1 - S_{22}\Gamma_L|^2} \qquad G_A = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)}{\left(1 - |\Gamma_{out}|^2\right)|1 - S_{11}\Gamma_S|^2}$$

$$G_T = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)\left(1 - |\Gamma_L|^2\right)}{|(1 - \Gamma_S\Gamma_{in})|^2|1 - S_{22}\Gamma_L|^2}$$

Roulette stability factor

$$k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|} \quad \text{and} \quad \Delta = S_{11}S_{22} - S_{12}S_{21}$$

Output and Input stability circles parameters center and radius

$$r_{out} = \frac{|S_{12}S_{21}|}{\left||S_{22}|^2 - |\Delta|^2\right|} \qquad C_{out} = \frac{\left(S_{22} - S_{11}^*\Delta\right)^*}{|S_{22}|^2 - |\Delta|^2}$$

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$$r_{in} = \frac{\left|S_{12}S_{21}\right|}{\left|\left|S_{11}\right|^2 - \left|\Delta\right|^2\right|} \qquad C_{in} = \frac{\left(S_{11} - S_{22}^*\Delta\right)^*}{\left|S_{11}\right|^2 - \left|\Delta\right|^2}$$

Source & Load transmission coefficient for maximum gain (conjugate matching)

$$\Gamma_{Sm} = \frac{B_1 - \sqrt{B_1^2 - 4\left|C_1\right|^2}}{2C_1} \qquad \Gamma_{Lm} = \frac{B_2 - \sqrt{B_2^2 - 4\left|C_2\right|^2}}{2C_2}$$

$$B_1 = 1 + \left|S_{11}\right|^2 - \left|S_{22}\right|^2 - \left|\Delta\right|^2 \qquad C_1 = S_{11} - \Delta S_{22}^*$$

$$B_2 = 1 + \left|S_{22}\right|^2 - \left|S_{11}\right|^2 - \left|\Delta\right|^2 \qquad C_2 = S_{22} - \Delta S_{11}^*$$

Low noise amplifier design parameters:

$$F = F_{\min} + \frac{4R_N}{Z_0}\frac{\left|\Gamma_S - \Gamma_{opt}\right|^2}{\left(1 - \left|\Gamma_S\right|^2\right) \times \left|1 + \Gamma_{opt}\right|^2} \qquad C_F = \frac{\Gamma_{opt}}{N+1}$$

$$R_F = \frac{\sqrt{N\left(N + 1 - \left|\Gamma_{opt}\right|^2\right)}}{N+1} \qquad N = \frac{F - F_{\min}}{4R_N / Z_o}\left|1 + \Gamma_{opt}\right|^2$$

The center and radius of constant Power Gain Circle:

$$T_{G_P} = \frac{-g_2\,\mathrm{Re}(C_2)}{-1 - \left|s_{22}\right|^2 g_2 + \left|D\right|^2 g_2} + j\frac{g_2\,\mathrm{Im}(C_2)}{-1 - \left|s_{22}\right|^2 g_2 + \left|D\right|^2 g_2}$$

$$R_{G_P} = \frac{\sqrt{1 - 2K\left|s_{12}s_{21}\right|g_2 + \left|s_{12}s_{21}\right|^2 g_2^{\,2}}}{\left|-1 - \left|s_{22}\right|^2 g_2 + \left|D\right|^2 g_2\right|} \quad \text{where} \quad C_2 = s_{22} - Ds_{11}^{\,*} \quad \text{and} \quad g_2 = \frac{G_P}{\left|s_{21}\right|^2}$$

The center and radius of constant Available Power Gain Circle:

$$T_{G_A} = \frac{g_1\,\mathrm{Re}(C_1)}{1 + \left|s_{11}\right|^2 g_1 - \left|D\right|^2 g_1} - j\frac{g_1\,\mathrm{Im}(C_1)}{1 + \left|s_{11}\right|^2 g_1 - \left|D\right|^2 g_1}$$

$$R_{G_A} = \frac{\sqrt{1 - 2K\left|s_{12}s_{21}\right|g_1 + \left|s_{12}s_{21}\right|^2 g_1^{\,2}}}{\left|1 + \left|s_{11}\right|^2 g_1 - \left|D\right|^2 g_1\right|} \quad \text{where} \quad C_1 = s_{11} - Ds_{22}^{\,*} \quad \text{and} \quad g_1 = \frac{G_A}{\left|s_{21}\right|^2}$$

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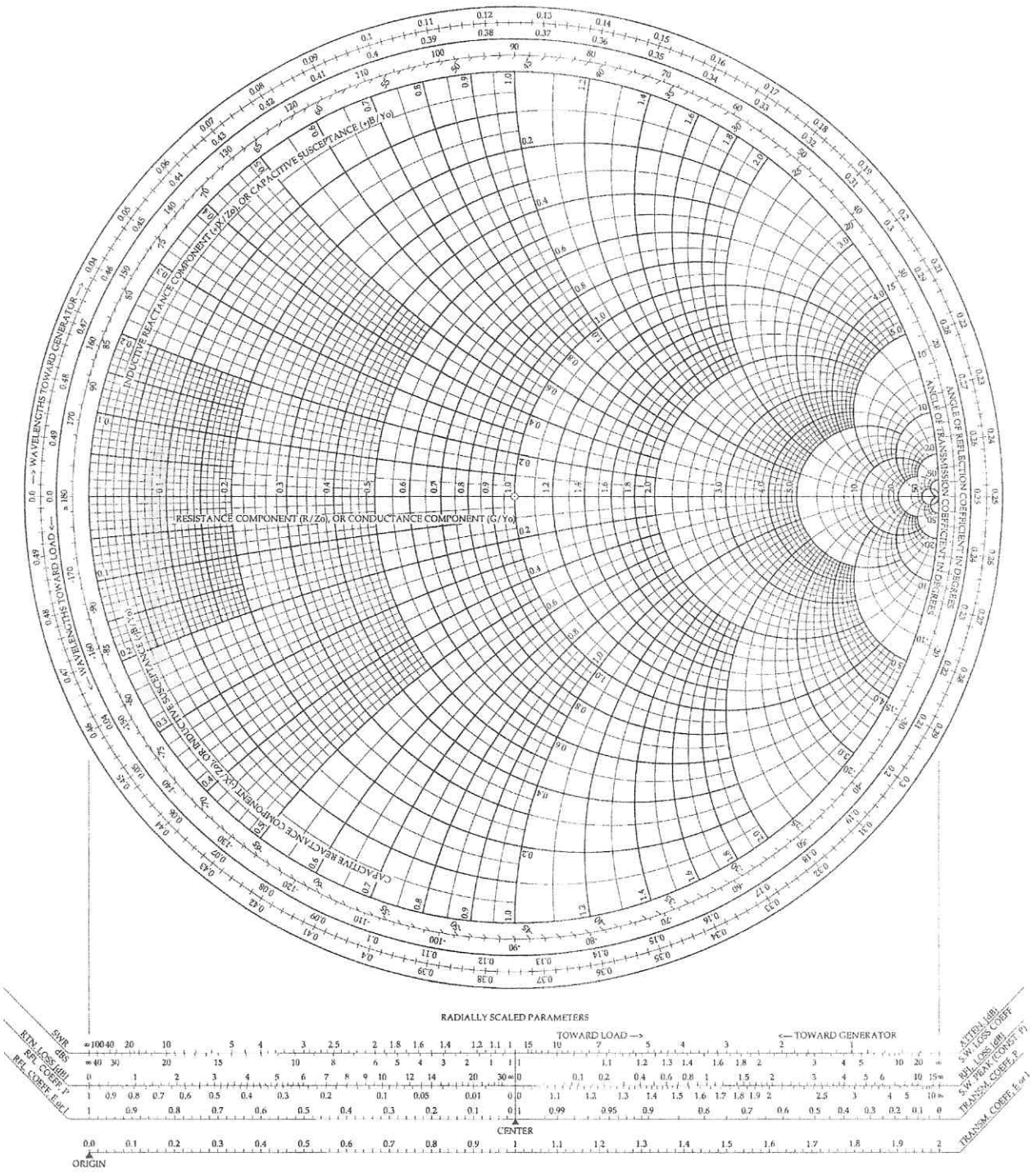
The Complete Smith Chart

Black Magic Design



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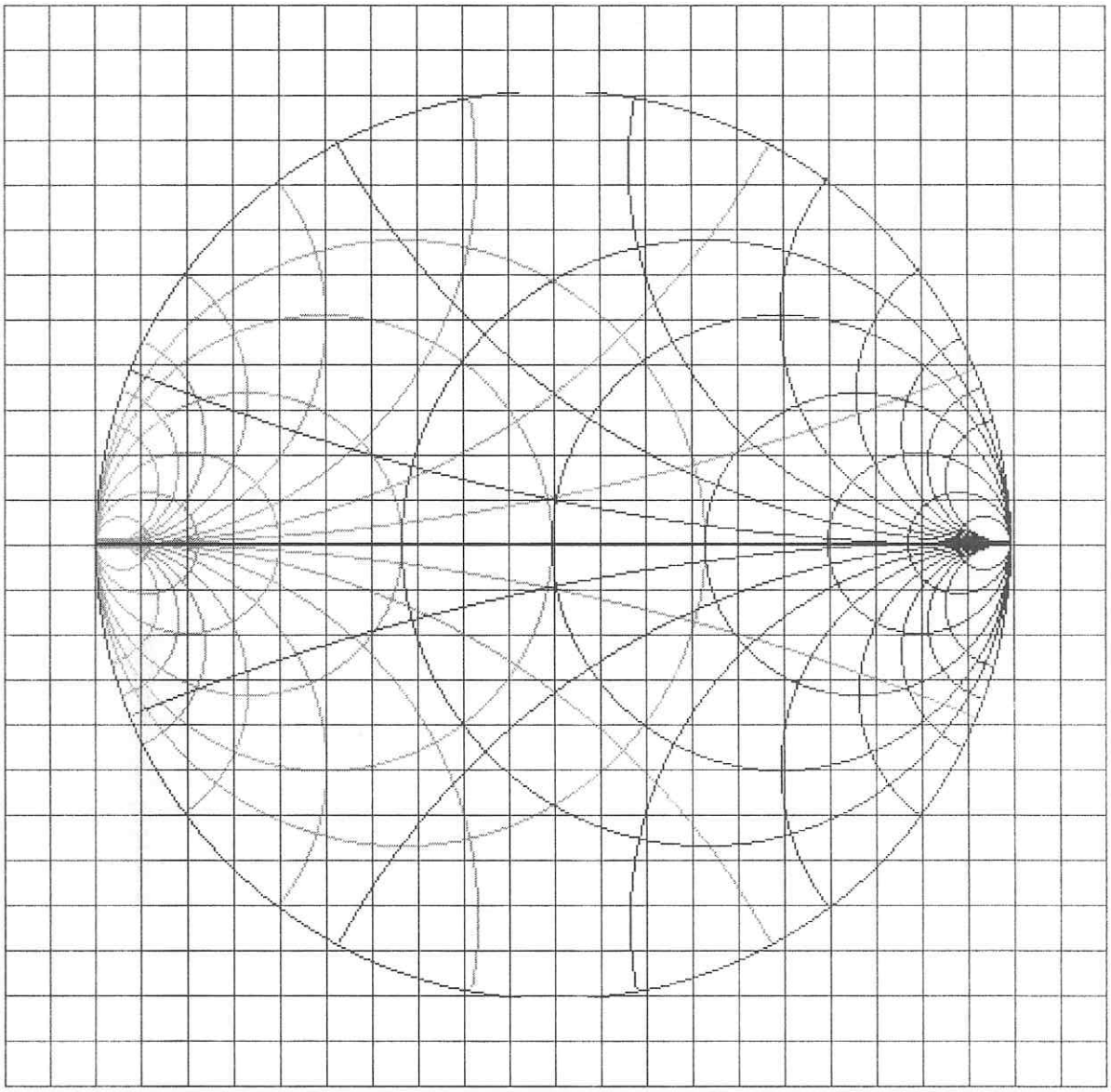

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